Lightning NO Production in the GMI Model

Kenneth E. Pickering
Dale J. Allen

Department of Meteorology
University of Maryland
College Park, MD

Outline

- Current procedure in GMI model
- Necessity of co-locating lightning NO with convective transport
- Parameterization development for GMI
- Implementation and Results

Current Procedure

- Climatological monthly spatial distributions of total (CG+IC) lightning flashes (Price et al., 1997) based on ISCCP deep convective cloud top heights (Price and Rind, 1992).
- CG fraction based on cold cloud depth (Price and Rind, 1993)
- $P_{CG} = 10\ P_{IC}$; $P_{CG} = 6.7 \times 10^{26}$ molec/flash or ~1100 moles/flash   (Price et al., 1997)
- Grid cell NO production values scaled such that global production equals a specified value (e.g., 5 TgN/yr)
- Vertically distributed according to C-shape profiles derived from cloud-resolving model simulations of Pickering et al. (1998)

Lightning NO and Convective Transport

- Use of climatological lightning NO production results in lightning NO not being injected into the model at same times and locations as at which the model convective transport occurs
- Therefore, lightning NO and convectively-transported species (HO_x precursors, NO_x, CO, NMHC) are introduced to the upper troposphere in different locations
- Results in "fuzzy" middle and upper tropospheric chemistry
- Lightning and convection need to be co-located!

Available Parameterizations

LIGHTNING FLASH RATES MUST BE PARAMETERIZED IN TERMS OF VARIABLES FROM THE MODEL CONVECTIVE SCHEME

- Cloud-height-based approach

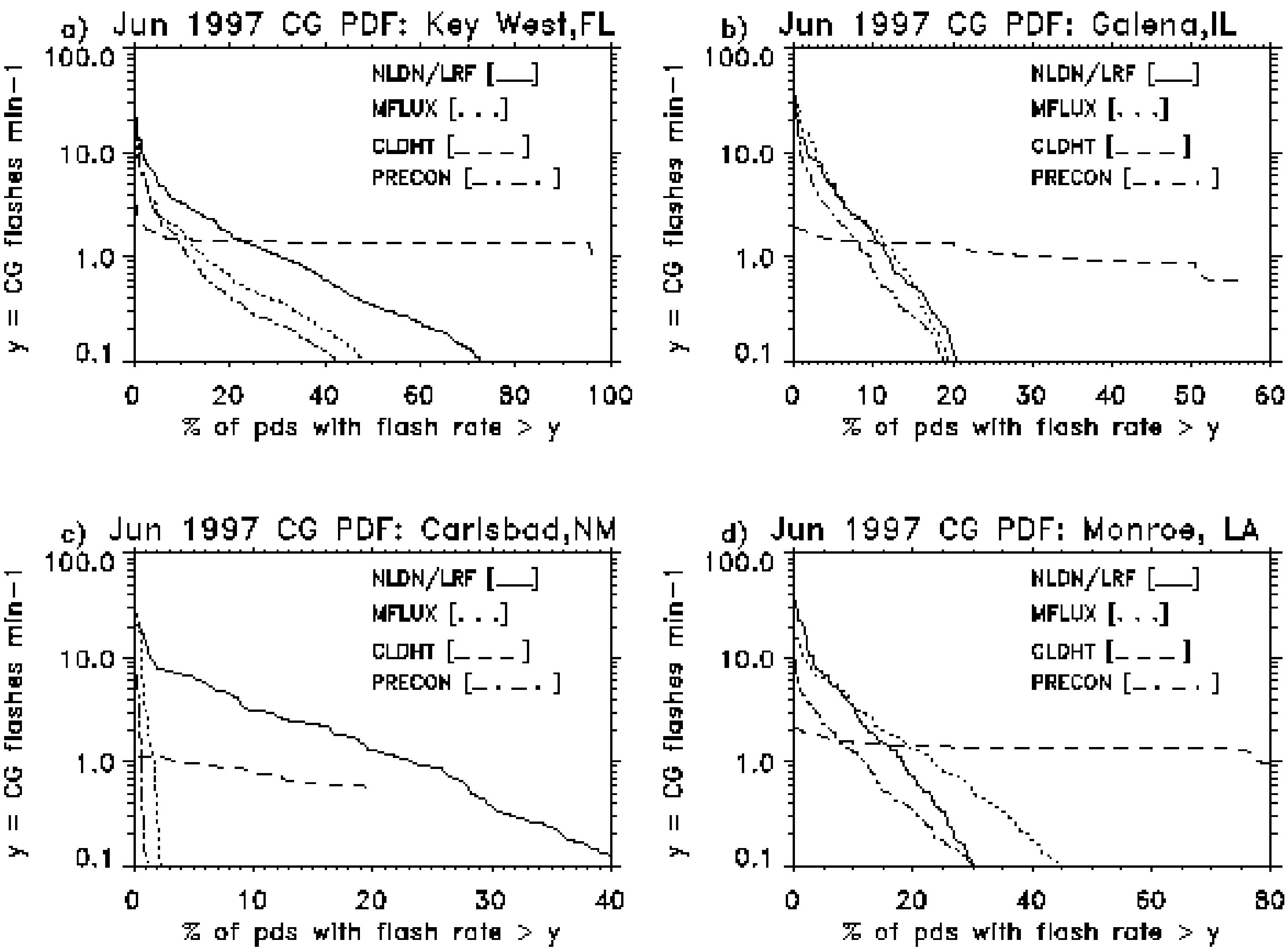
  Price and Rind (1992)

- Cloud-mass flux based approach

  Allen and Pickering (2002)

- Convective precipitation based approach

  Allen and Pickering (2002)



a) Jun 1997 CG PDF: Key West,FL
b) Jun 1997 CG PDF: Galena,IL
c) Jun 1997 CG PDF: Carlsbad,NM
d) Jun 1997 CG PDF: Monroe, LA
NLDN/LRF [___]
MFLUX [. . .]
CLDHT [_ _ _]
PRECON [_ . _ .]
y = CG flashes min−1
% of pds with flash rate > y
100.0
10.0
1.0
0.1

Figure 12

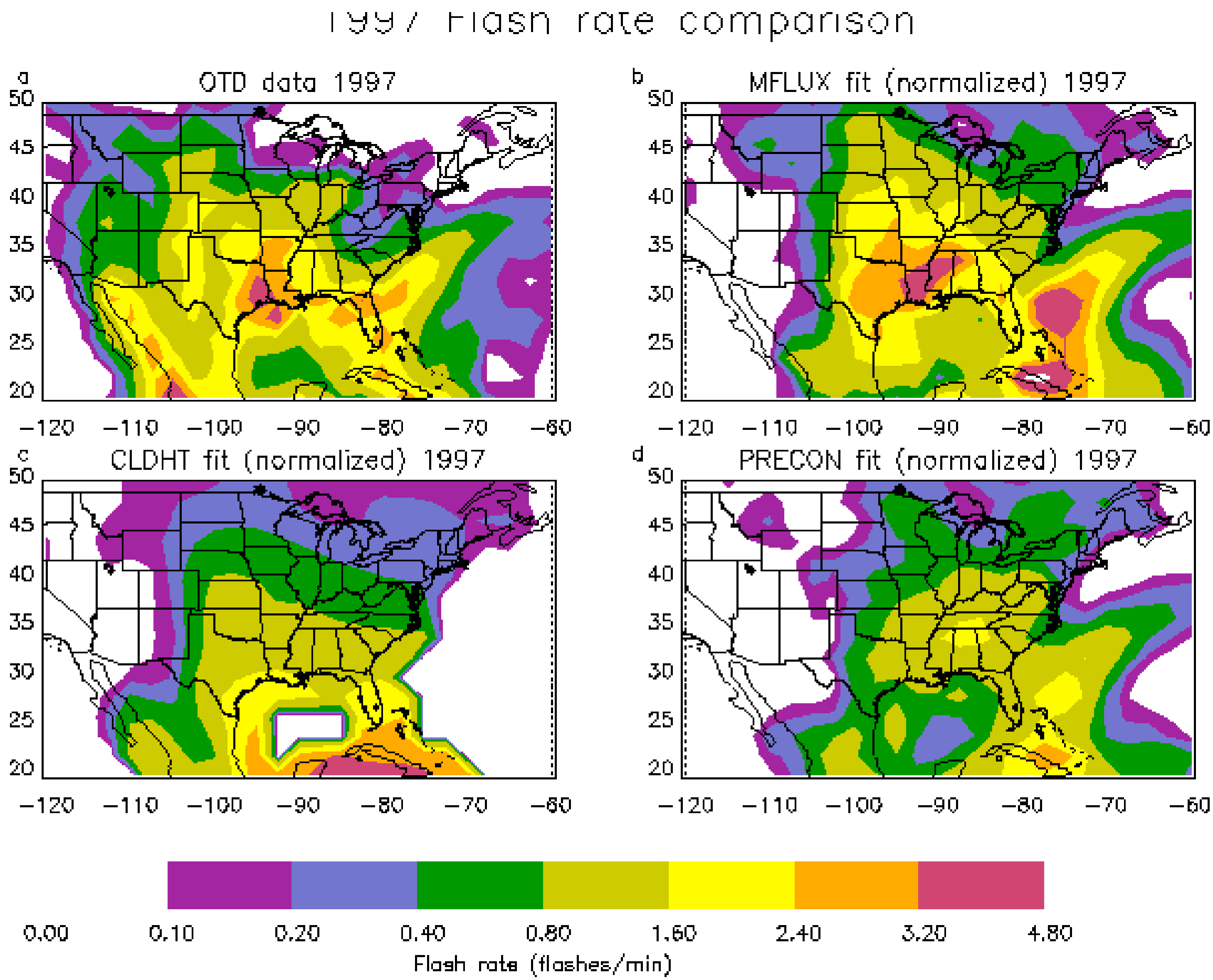

1997 Flash rate comparison
a
OTD data 1997
b
MFLUX fit (normalized) 1997
c
CLDHT fit (normalized) 1997
d
PRECON fit (normalized) 1997
50
45
40
35
30
25
20
−120 −110 −100 −90 −80 −70 −60
0.00 0.10 0.20 0.40 0.80 1.60 2.40 3.20 4.80
Flash rate (flashes/min)

Figure 11

Other Changes

Evidence is mounting that refutes the assumption that $P_{CG} = 10\, P_{IC}$. We are now assuming $P_{CG} \sim P_{IC}$.

Storm	P_{IC}/P_{CG}	
STERAO - 7/12	0.75-1.0	DeCaria et al.(2000, 2004)
STERAO – 7/10	0.6	Ott et al. (2004)
EULINOX – 7/21	1.0	Ott et al. (2002)
	1.4	Fehr et al. (2004)
CRYSTAL-FACE		
7/29	0.5-1.0	Ott et al. (2004)
7/16	1.0	Ott et al. (2004)

Other Changes

Estimates of IC/CG flash ratio not necessary.

Boccippio et al. (2002) analysis of IC/CG ratio over U.S. based on OTD and NLDN indicates that storm intensity, morphology, and level of organization have much more impact on IC/CG ratios than environmental variables that can be extracted from GCM output.

CG flashes estimated from cloud mass fluxes will be scaled up to total flashes based on OTD/LIS climatology.

Step 1: Polynomial construction

- **Data**: NLDN/LRF 6-hr avg 4º x 5º CG flash rates for 1997

- **Model output**: Convective mass flux (CLDMAS) at 0, 6, 12, +18 UT
- i=1: GMAO analyzed fields at ~353 hPa for Mar-Dec ‘97, Jan-Feb ‘98
- i=2: NCAR GCM-fields at ~369 hPa for “1997”
- i=3: GISS GCM-fields at ~504 hPa for “1977”
  - (374 hPa CLDMAS considered for GISS; (too few mid-latitude clouds)

- **Geographic Region**: 10º-60ºN; 120º-60ºW

Polynomial fit to normalized CLDMAS

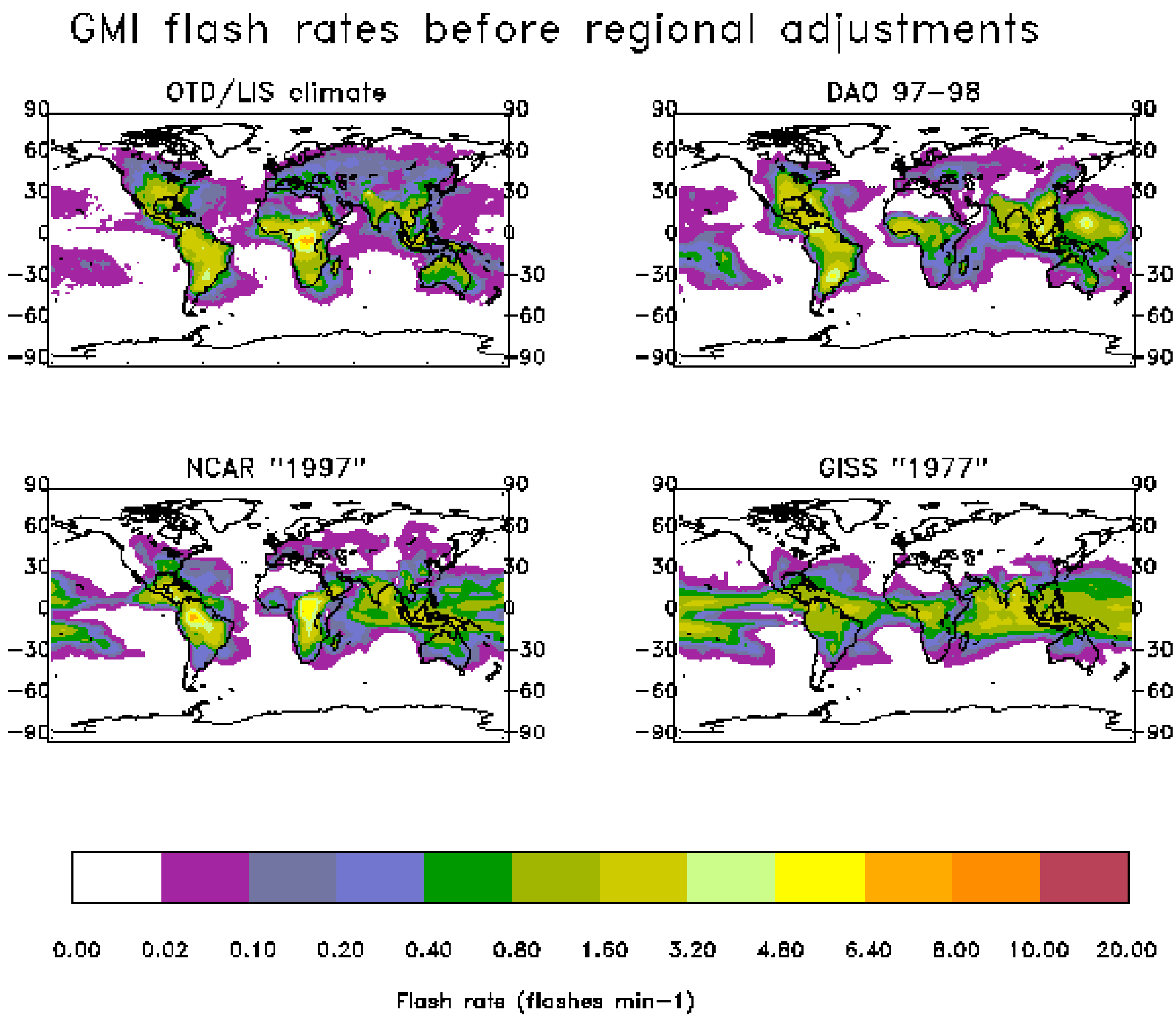
- 1. For 10º-60ºN, 120º-60ºW, extract 00, 06, 12, and 18 UT time-averaged CLDMAS at model-specific pressure levels

- 2. Normalize CLDMAS by dividing by model-dependent mean(CLDMAS)+2*sigma(CLDMAS)
- $x_i = CLDMAS_i / [mean(CLDMAS_i)+2*sigma(CLDMAS_i)]$
- y = NLDN/LRF CG flash rates

- 3. For i=1,3 do sort x_i and y independently by magnitude

- 4. For i=1,3 do fit polynomial ($y_{fit} = ax_i + b[x_i]^2+c[x_i]^3$)

- 5. Adjust y_{fit} for area of grid box; Constrain to be ≥ 0



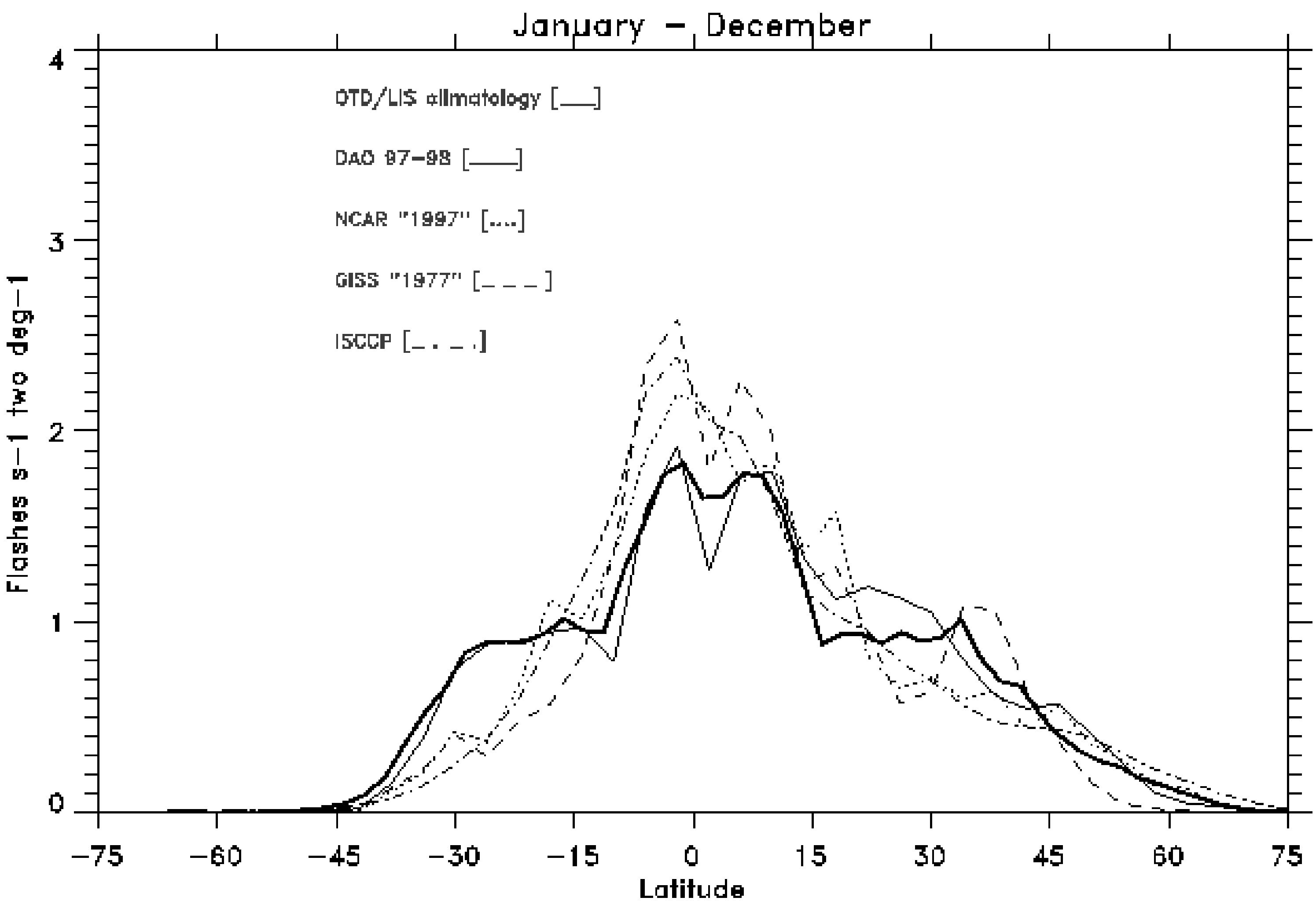
GMI flash rates before regional adjustments
OTD/LIS climate
DAO 97-98
NCAR "1997"
GISS "1977"
90
60
30
0
-30
-60
-90
0.00 0.02 0.10 0.20 0.40 0.80 1.60 3.20 4.80 6.40 8.00 10.00 20.00
Flash rate (flashes min-1)

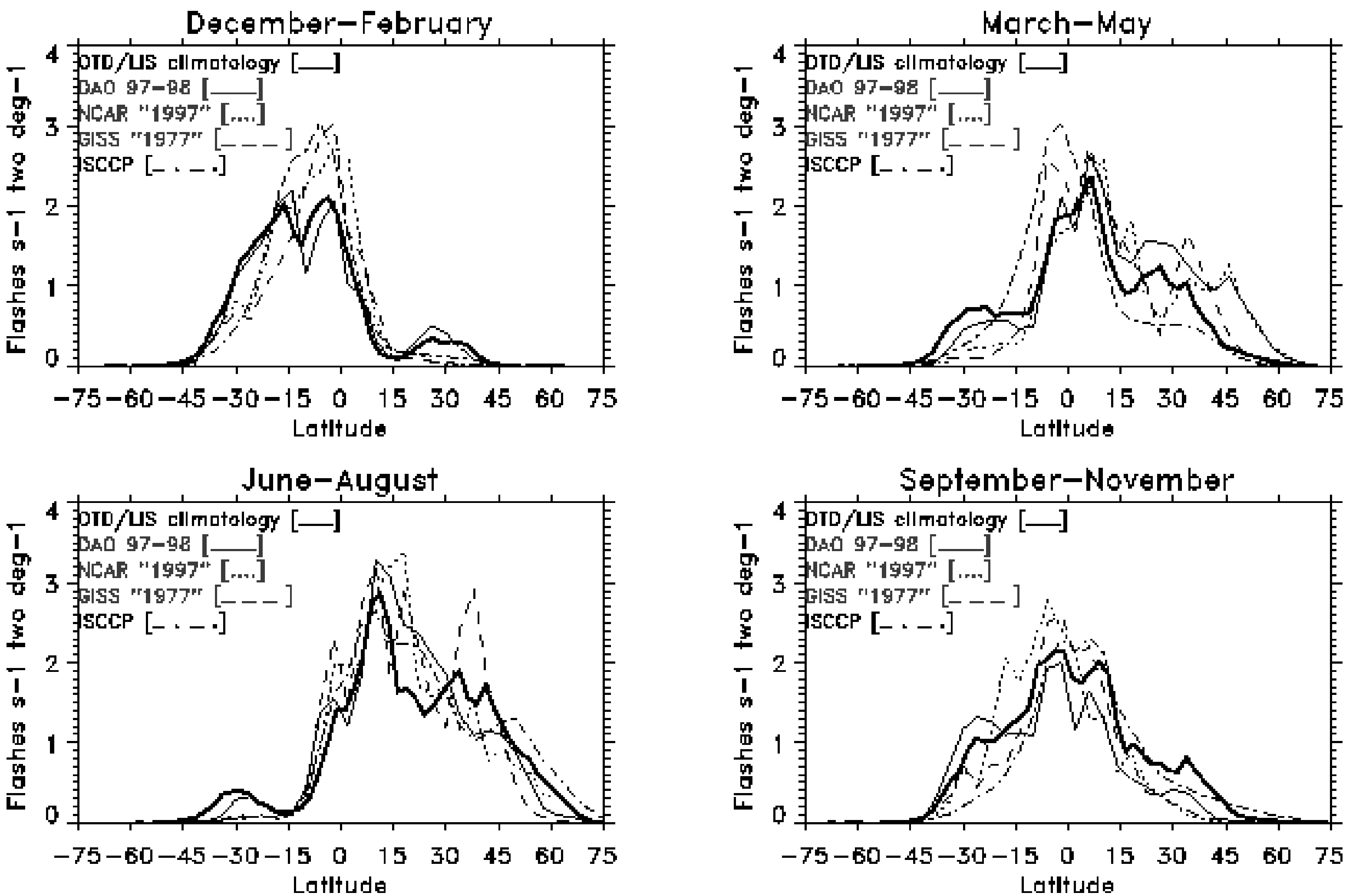
Step 2: Adjust flash rates to best match OTD/LIS climatology

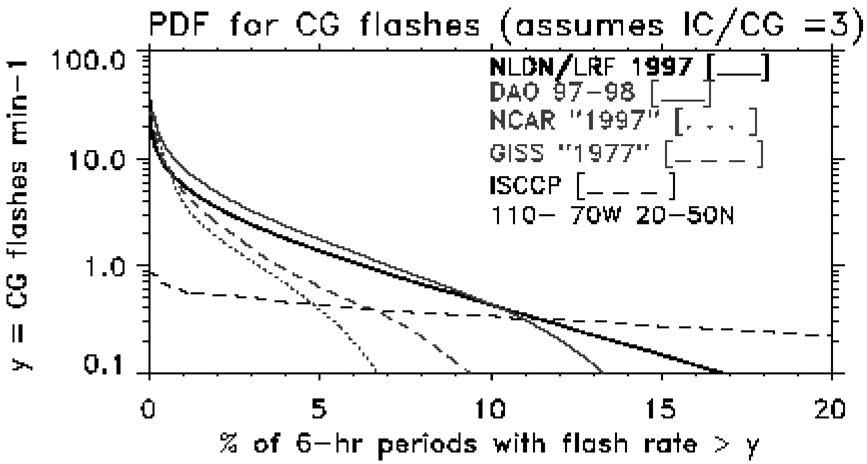
Marine-continental contrast not captured especially in the tropics.

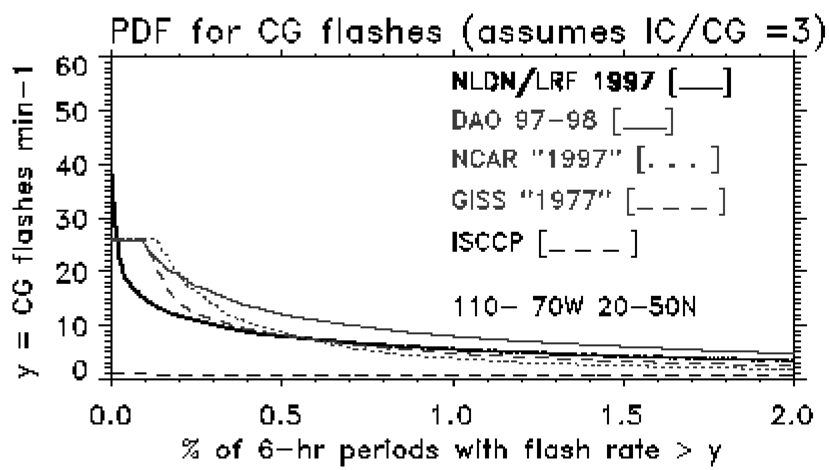
For i=1,3 do

1. Adjust global CG flash rates so that the annual average total global flash rate matches observed total flash rate from v1.0 OTD/LIS climatology (46.6 flashes s^{-1}) [see previous plot]
2. Reduce tropical marine flash rates to best match climatology
3. Increase tropical continental flash rates to best match climatology
4. Adjust midlatitude continental flash rates to best match climatology
5. Constrain flash rates to be < 100 flashes/min based on obs.
6. Adjust global flash rates to match climatology

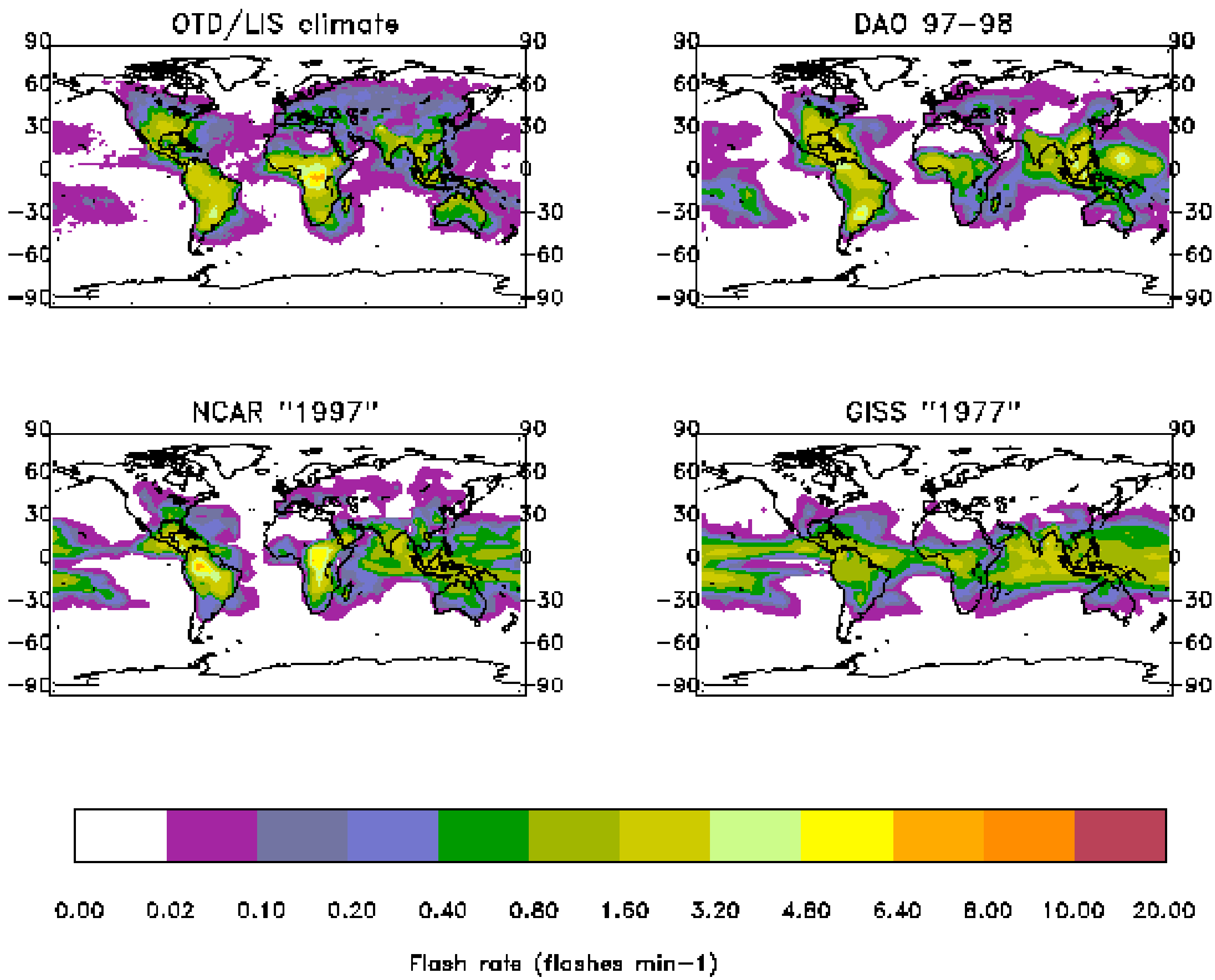

January – December
OTD/LIS climatology [___]
DAO 97-98 [____]
NCAR "1997" [....]
GISS "1977" [_ _ _]
ISCCP [_ . _ .]
Flashes s−1 two deg−1
Latitude
0
1
2
3
4
−75
−60
−45
−30
−15
0
15
30
45
60
75

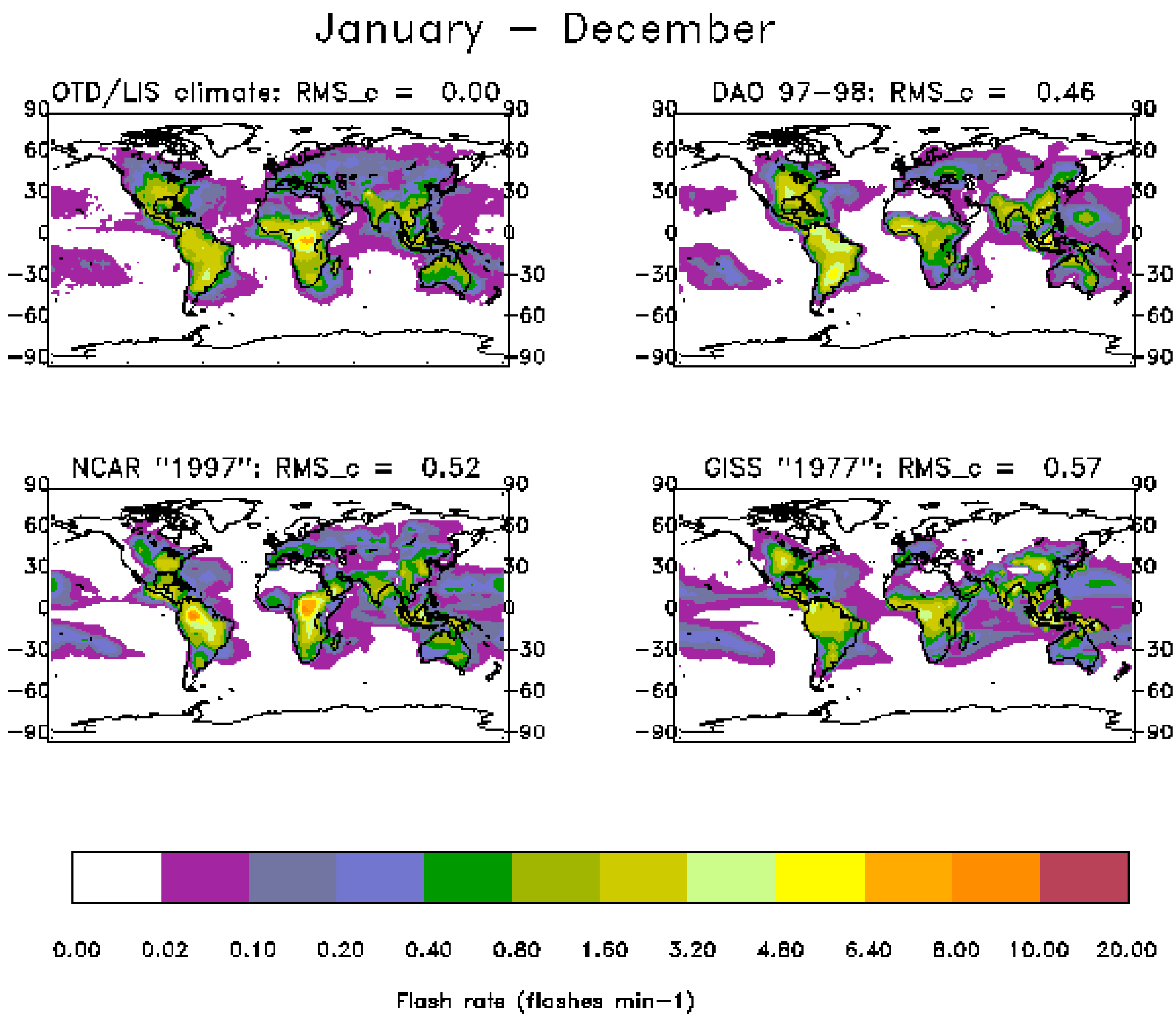

December−February
March−May
June−August
September−November
OTD/LIS climatology [___]
DAO 97−98 [____]
NCAR "1997" [....]
GISS "1977" [_ _ _]
ISCCP [_ . _ .]
Flashes s−1 two deg−1
Latitude
−75 −60 −45 −30 −15 0 15 30 45 60 75
0 1 2 3 4

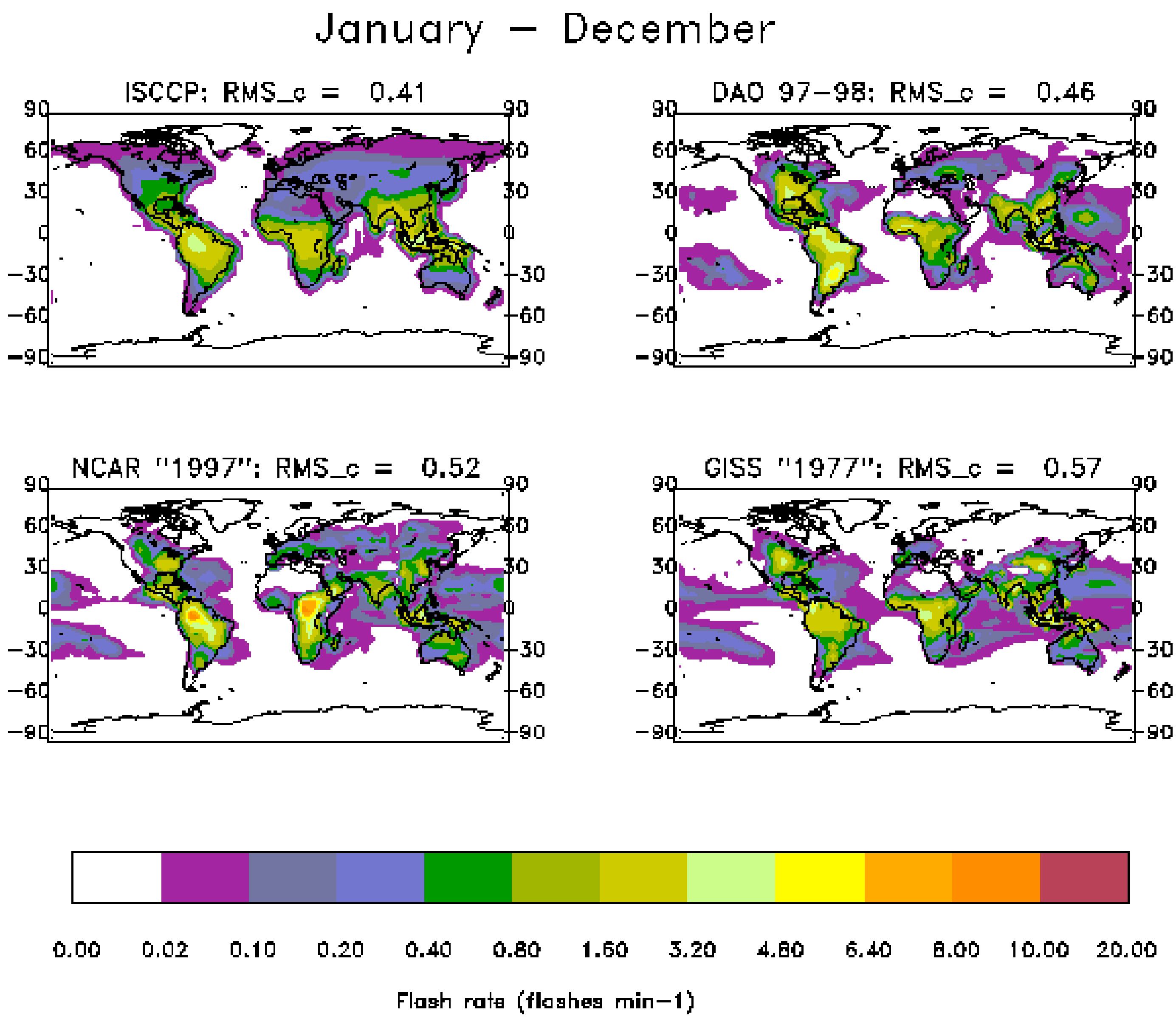

PDF for CG flashes (assumes IC/CG =3)
NLDN/LRF 1997 [___]
DAO 97-98 [___]
NCAR "1997" [. . .]
GISS "1977" [_ _ _]
ISCCP [_ _ _]
110- 70W 20-50N
y = CG flashes min-1
100.0
10.0
1.0
0.1
0
5
10
15
20
% of 6-hr periods with flash rate > y

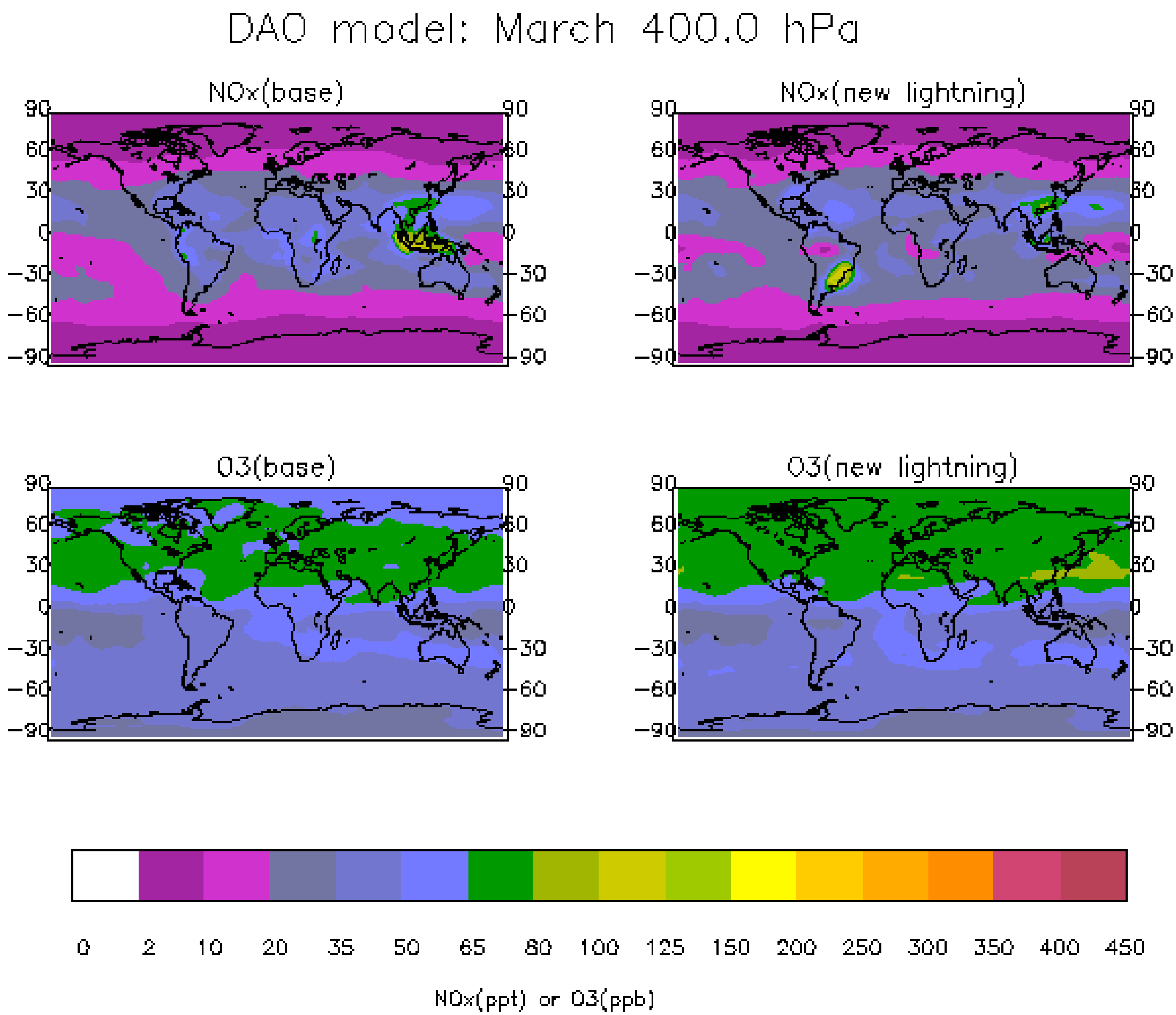

PDF for CG flashes (assumes IC/CG =3)
NLDN/LRF 1997 [___]
DAO 97-98 [___]
NCAR "1997" [. . .]
GISS "1977" [_ _ _]
ISCCP [_ _ _]
110- 70W 20-50N
y = CG flashes min-1
60
50
40
30
20
10
0
0.0
0.5
1.0
1.5
2.0
% of 6-hr periods with flash rate > y

GMI flash rates before regional adjustments

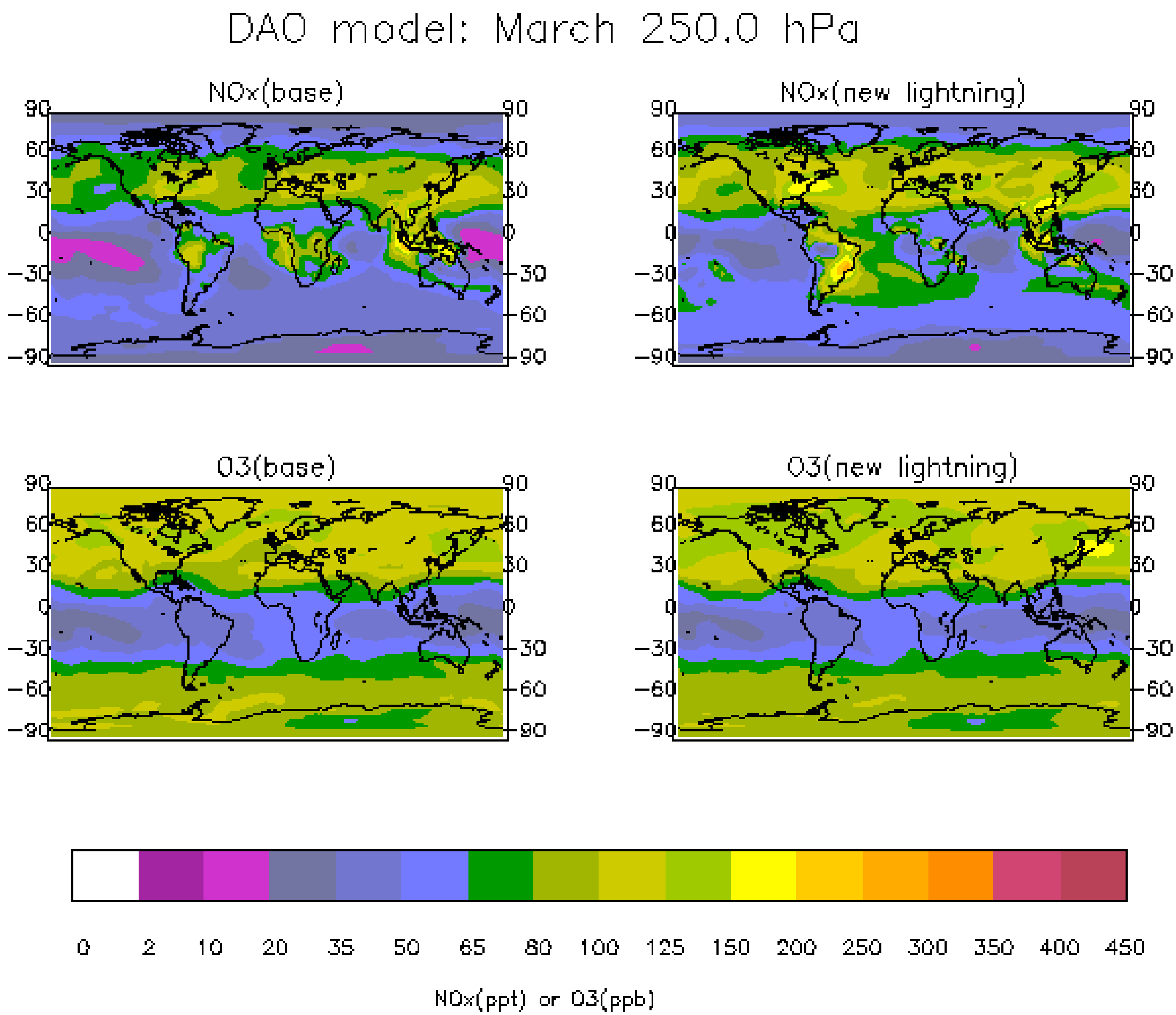


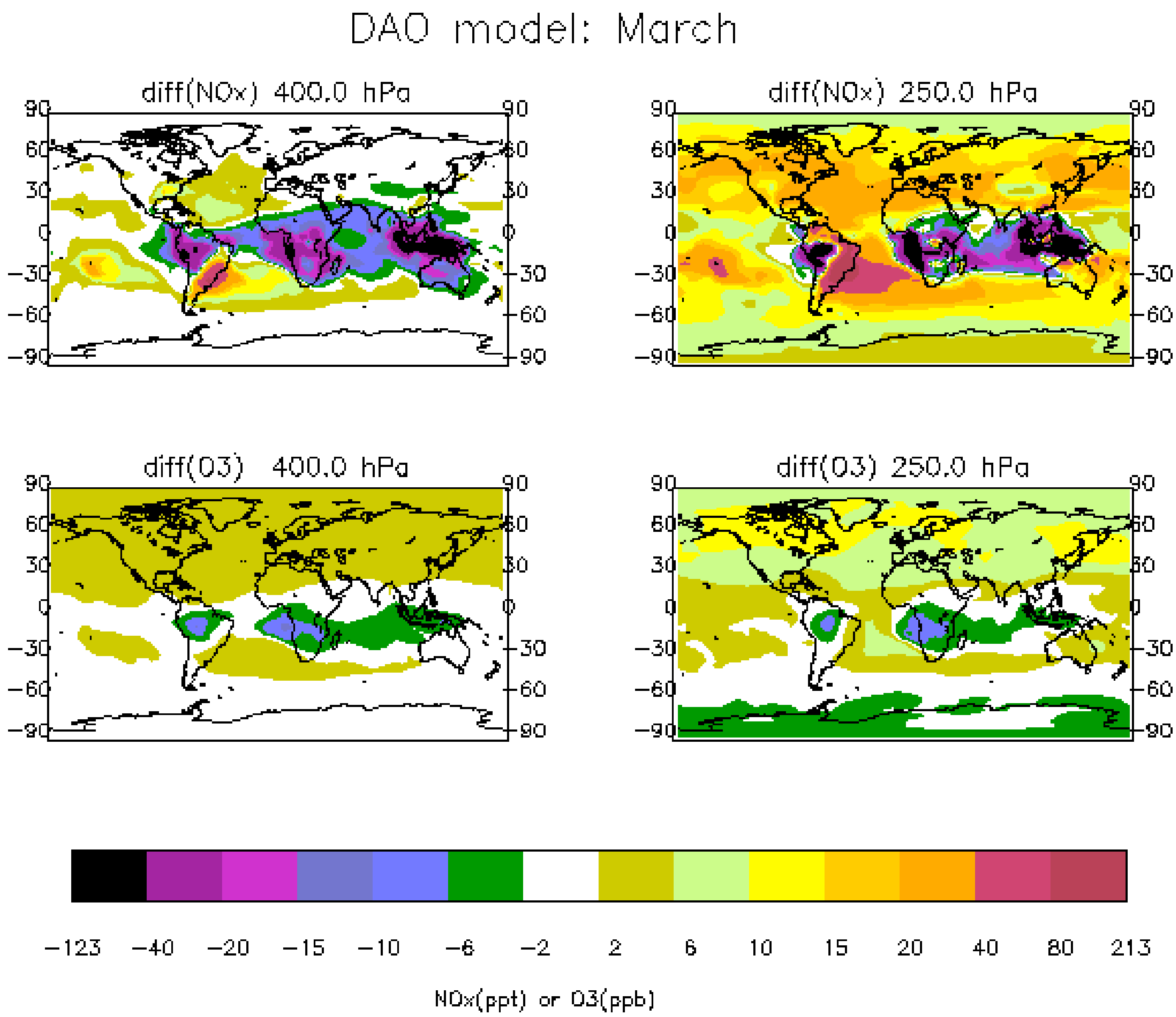

January – December
OTD/LIS climate: RMS_c = 0.00
DAO 97-98: RMS_c = 0.46
NCAR "1997": RMS_c = 0.52
GISS "1977": RMS_c = 0.57
90
60
30
0
-30
-60
-90
0.00
0.02
0.10
0.20
0.40
0.80
1.60
3.20
4.80
6.40
8.00
10.00
20.00
Flash rate (flashes min-1)

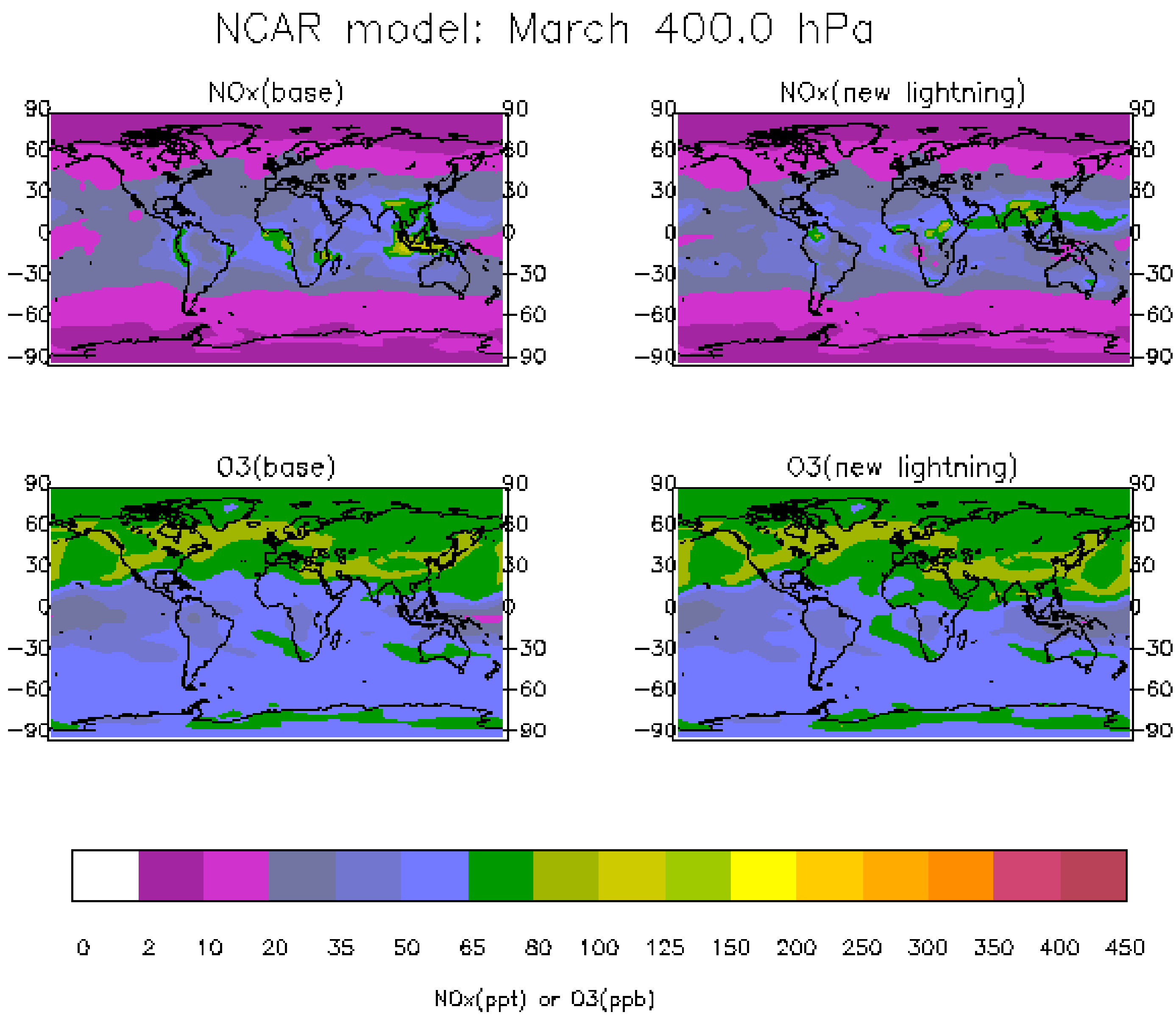

January – December
ISCCP: RMS_c = 0.41
DAO 97-98: RMS_c = 0.46
NCAR "1997": RMS_c = 0.52
GISS "1977": RMS_c = 0.57
0.00
0.02
0.10
0.20
0.40
0.80
1.60
3.20
4.80
6.40
8.00
10.00
20.00
Flash rate (flashes min-1)



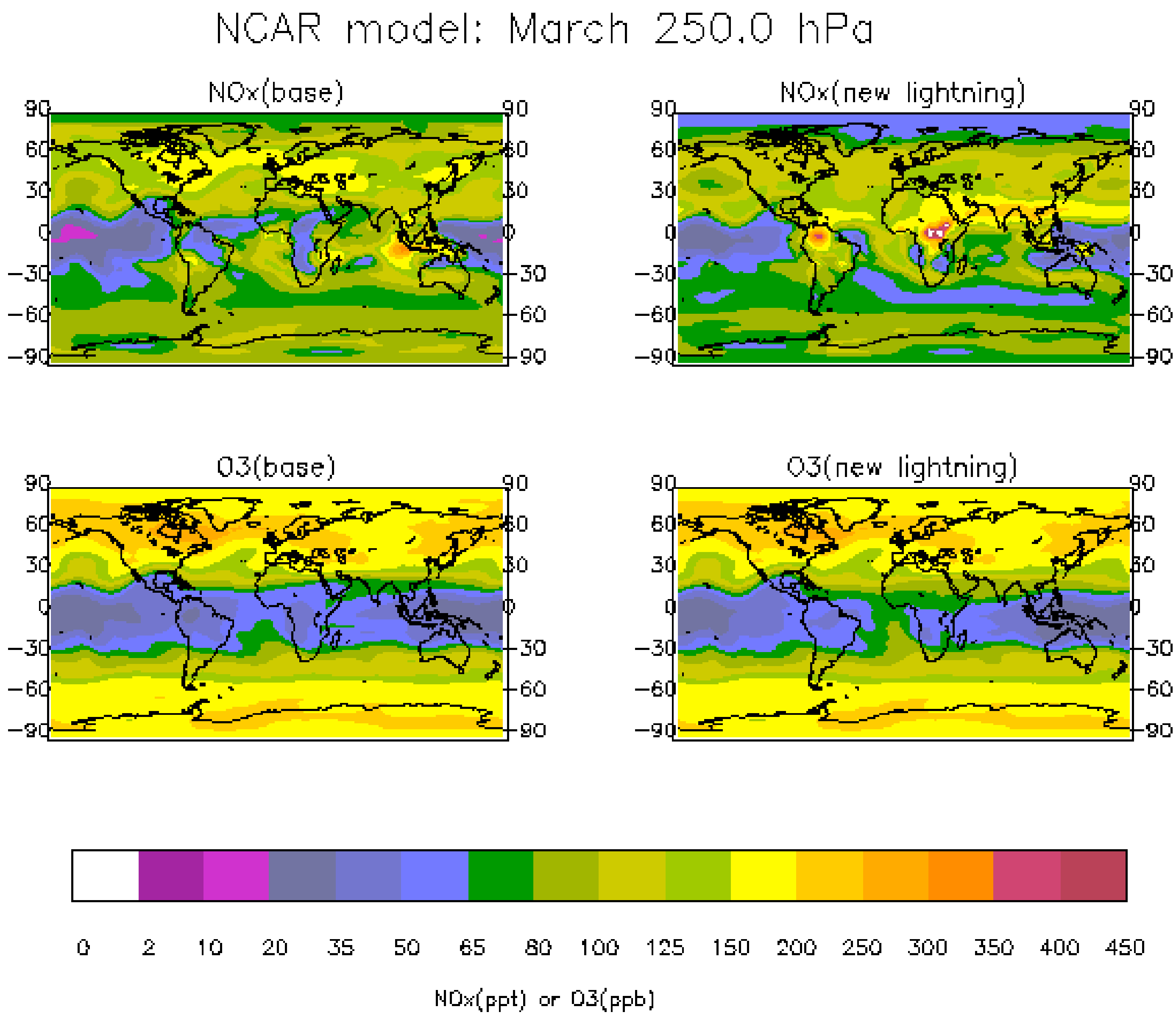
DAO model: March 400.0 hPa
NOx(base)
NOx(new lightning)
O3(base)
O3(new lightning)
90
60
30
0
−30
−60
−90
0 2 10 20 35 50 65 80 100 125 150 200 250 300 350 400 450
NOx(ppt) or O3(ppb)

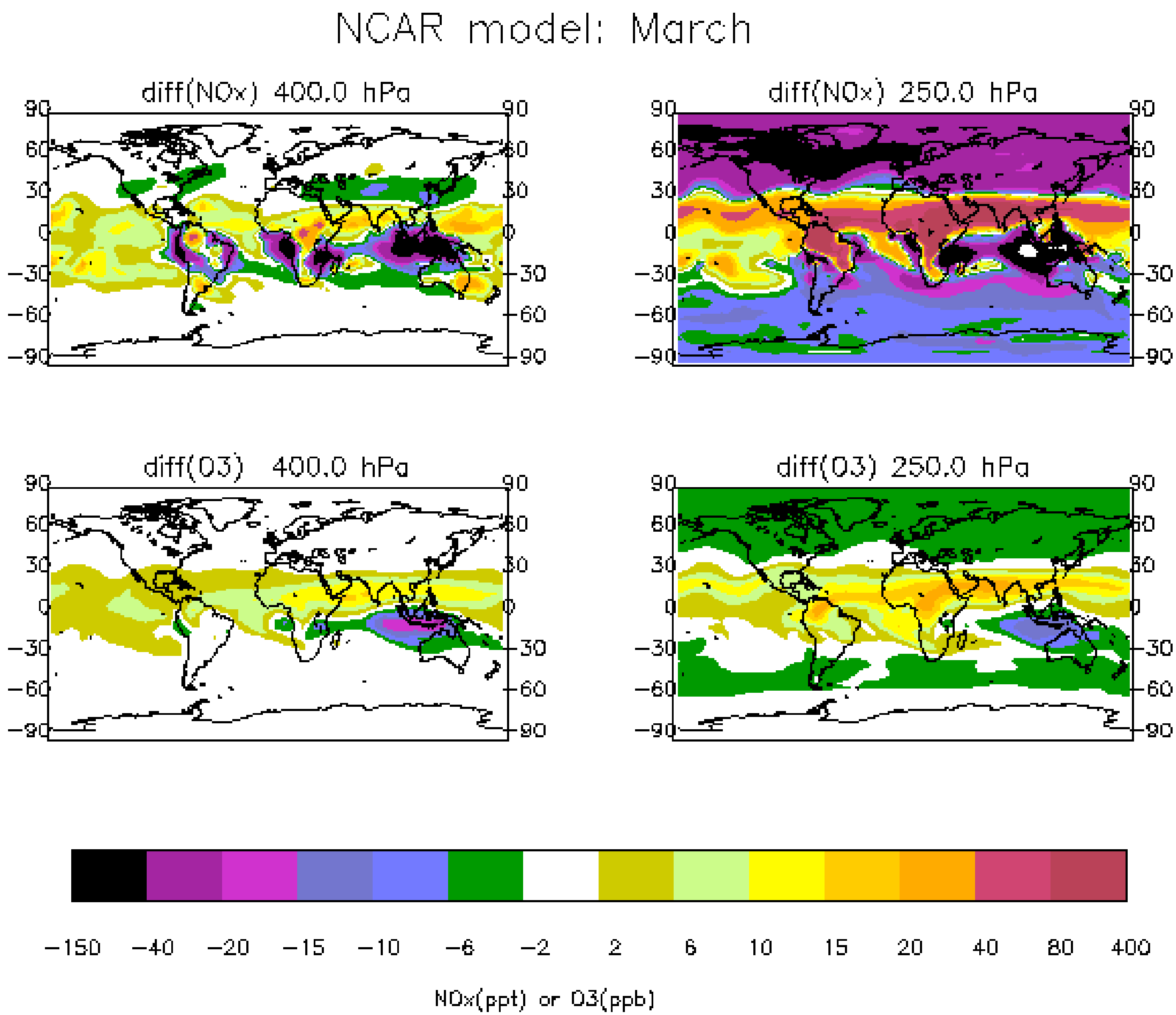

DAO model: March 250.0 hPa
NOx(base)
NOx(new lightning)
O3(base)
O3(new lightning)
90
60
30
0
−30
−60
−90
0
2
10
20
35
50
65
80
100
125
150
200
250
300
350
400
450
NOx(ppt) or O3(ppb)

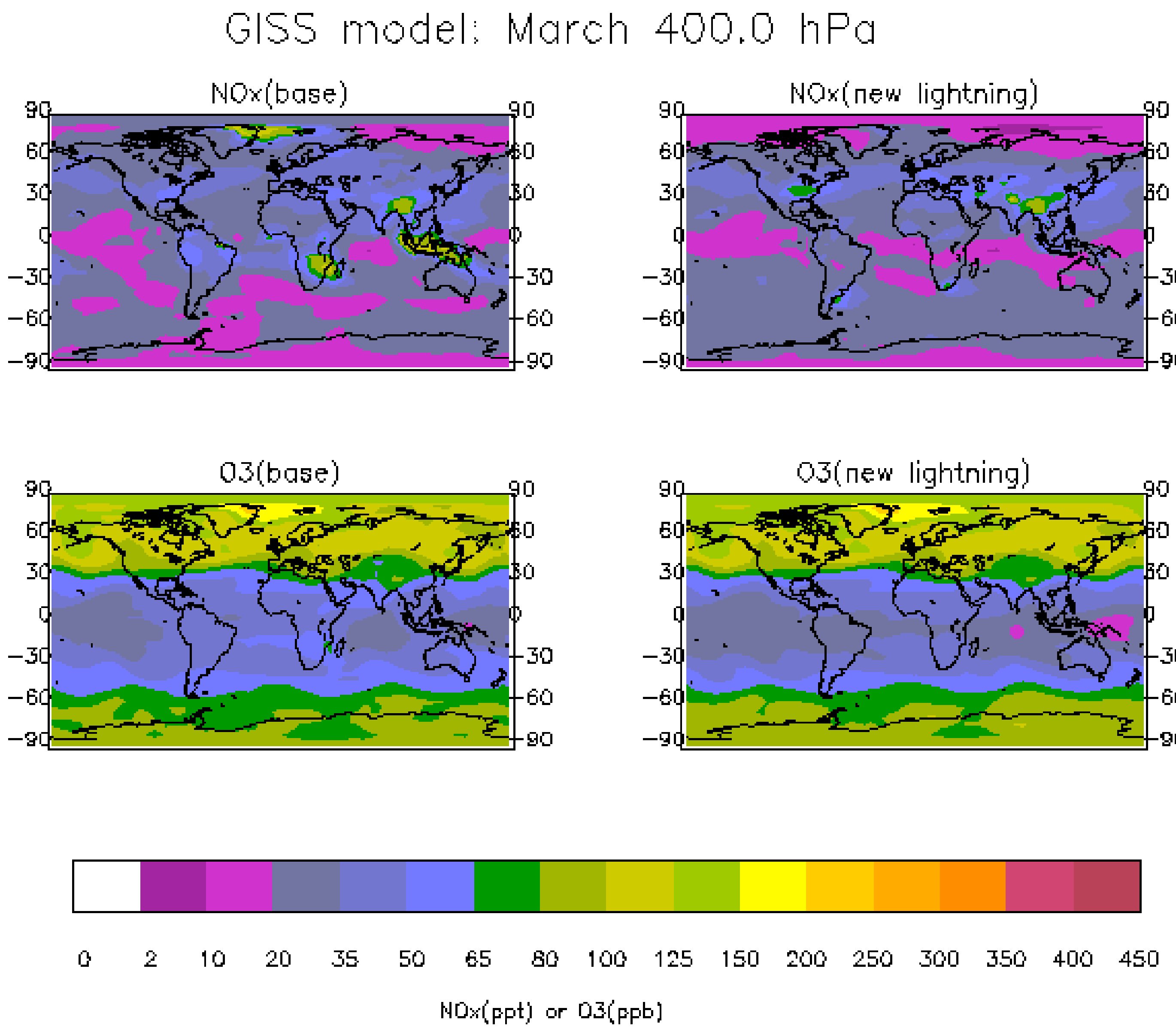

DAO model: March
diff(NOx) 400.0 hPa
diff(NOx) 250.0 hPa
diff(O3) 400.0 hPa
diff(O3) 250.0 hPa
90
60
30
0
−30
−60
−90
−123 −40 −20 −15 −10 −6 −2 2 6 10 15 20 40 80 213
NOx(ppt) or O3(ppb)



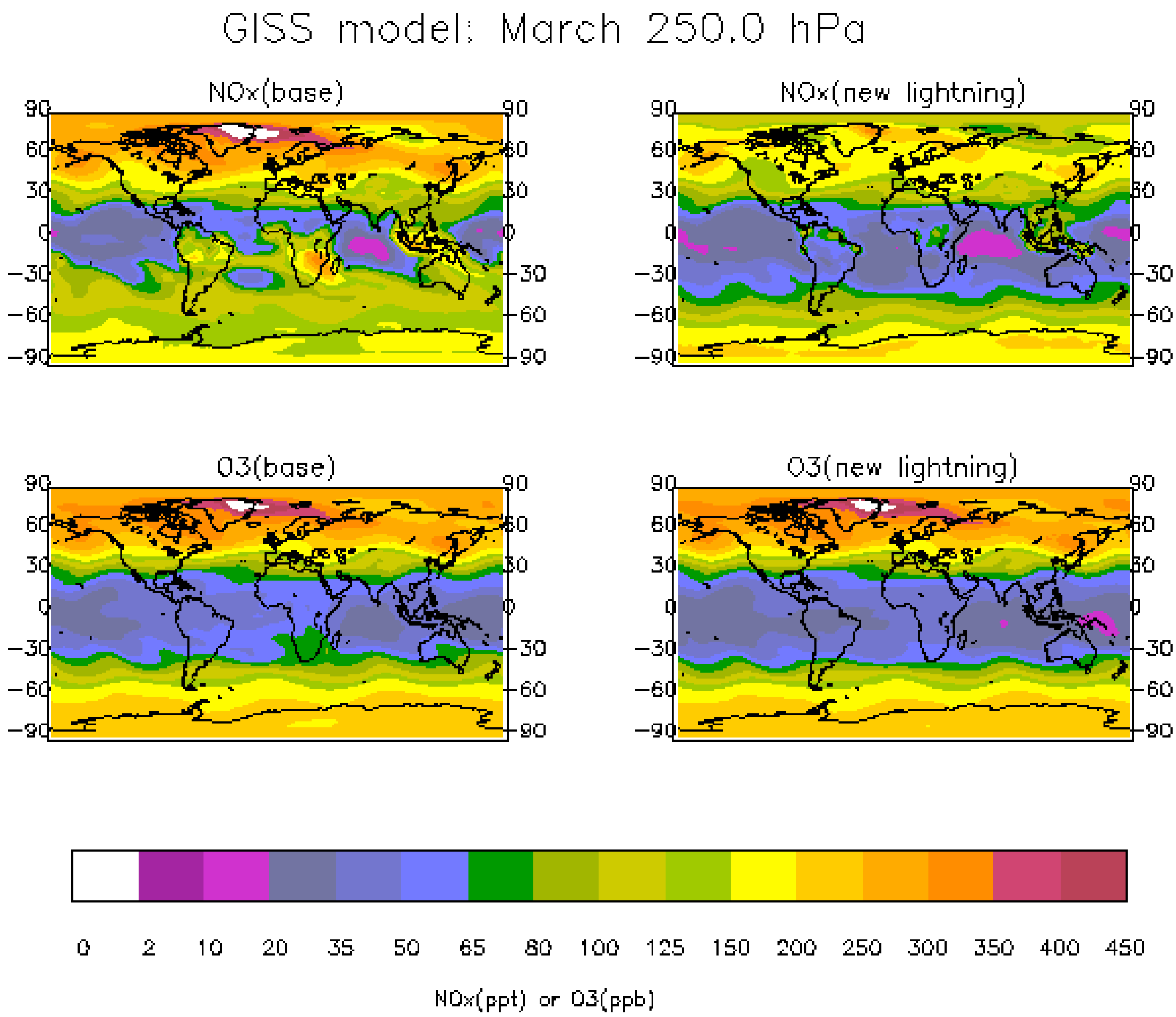
NCAR model: March 400.0 hPa
NOx(base)
NOx(new lightning)
O3(base)
O3(new lightning)
90
60
30
0
−30
−60
−90
0
2
10
20
35
50
65
80
100
125
150
200
250
300
350
400
450
NOx(ppt) or O3(ppb)


NCAR model: March 250.0 hPa
NOx(base)
NOx(new lightning)
O3(base)
O3(new lightning)
90 60 30 0 −30 −60 −90
0 2 10 20 35 50 65 80 100 125 150 200 250 300 350 400 450
NOx(ppt) or O3(ppb)

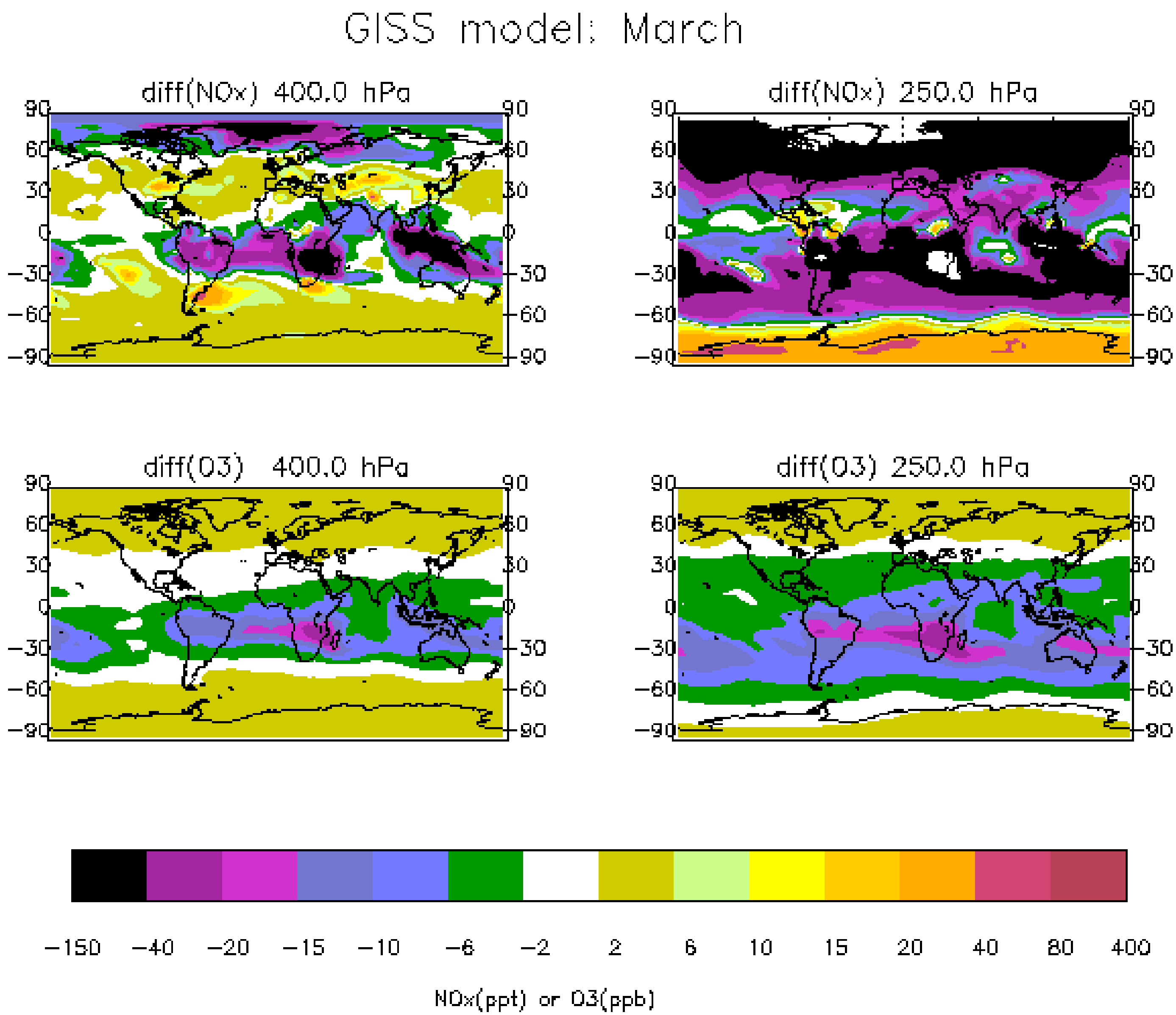

NCAR model: March
diff(NOx) 400.0 hPa
diff(NOx) 250.0 hPa
diff(O3) 400.0 hPa
diff(O3) 250.0 hPa
90
60
30
0
−30
−60
−90
−150
−40
−20
−15
−10
−6
−2
2
6
10
15
20
40
80
400
NOx(ppt) or O3(ppb)



GISS model: March 400.0 hPa
NOx(base)
NOx(new lightning)
O3(base)
O3(new lightning)
90
60
30
0
−30
−60
−90
0 2 10 20 35 50 65 80 100 125 150 200 250 300 350 400 450
NOx(ppt) or O3(ppb)



GISS model: March 250.0 hPa
NOx(base)
NOx(new lightning)
O3(base)
O3(new lightning)
90
60
30
0
−30
−60
−90
0
2
10
20
35
50
65
80
100
125
150
200
250
300
350
400
450
NOx(ppt) or O3(ppb)


GISS model: March
diff(NOx) 400.0 hPa
diff(NOx) 250.0 hPa
diff(O3) 400.0 hPa
diff(O3) 250.0 hPa
90
60
30
0
−30
−60
−90
−150 −40 −20 −15 −10 −6 −2 2 6 10 15 20 40 80 400
NOx(ppt) or O3(ppb)

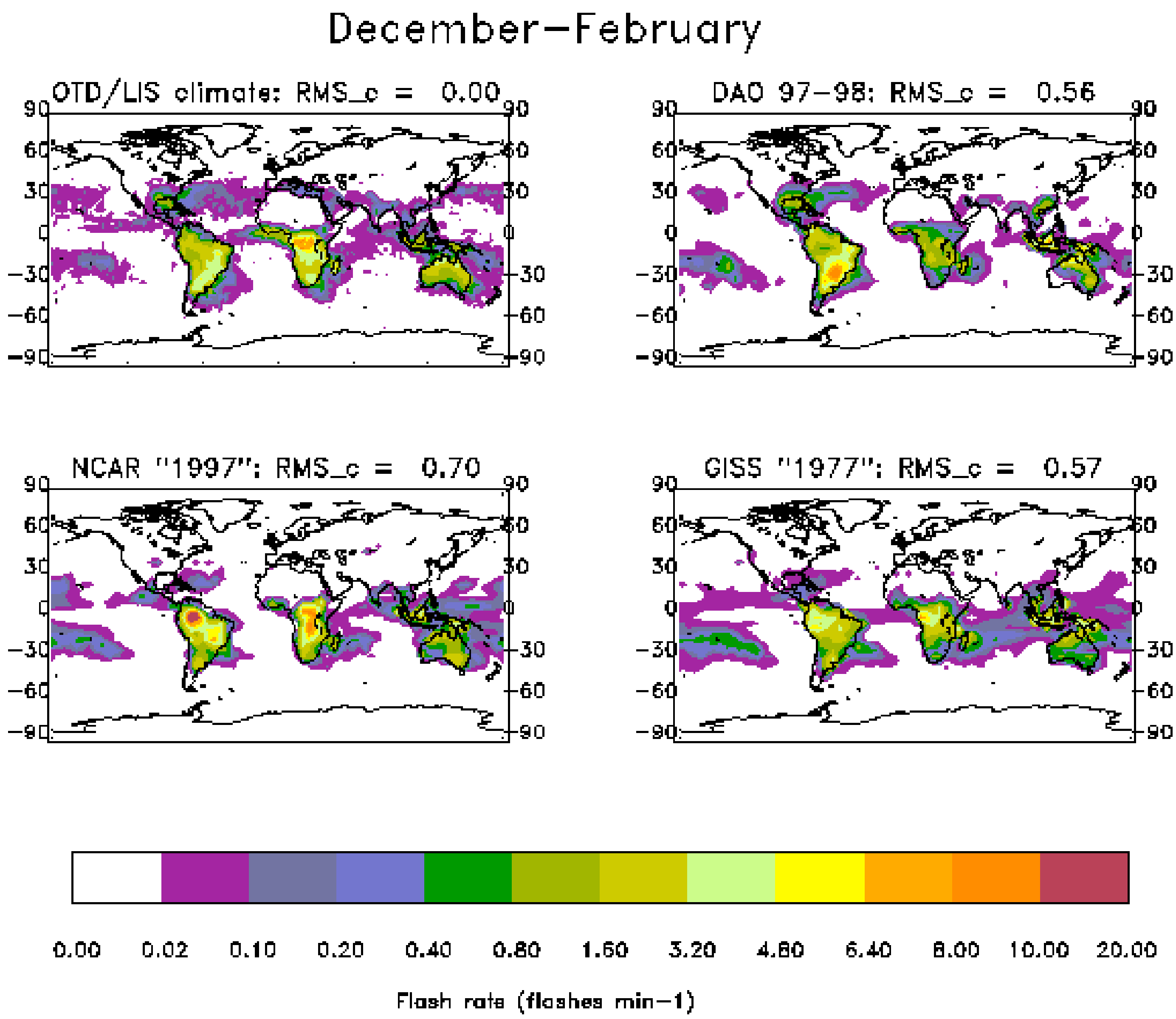
Summary

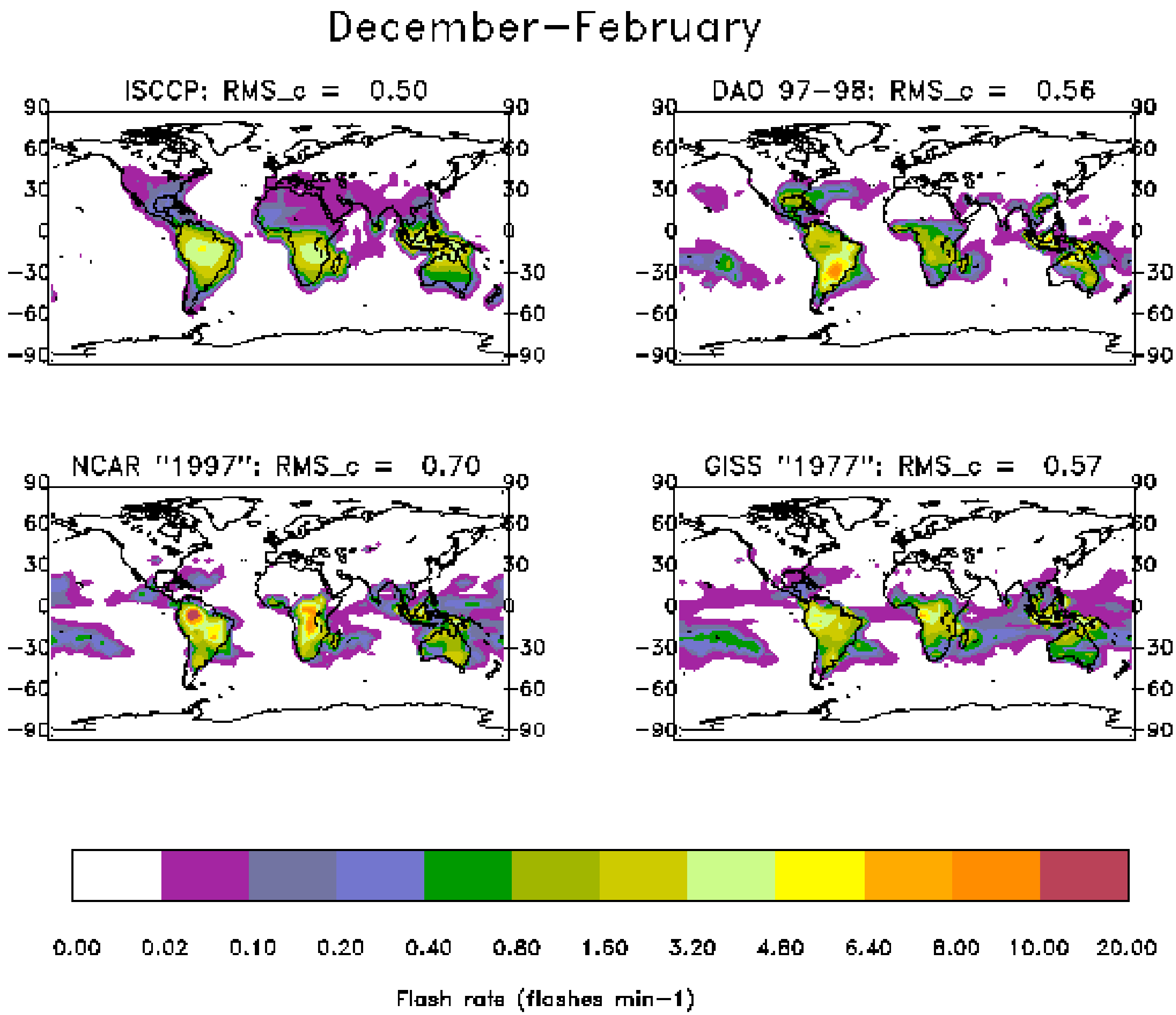
- Relationship between NLDN/LRF and normalized CLDMAS was used to derive lightning parameterizations for each of the three met. fields used by GMI.
- Flash rates at tropical marine locations were too high (normalized so that tropical marine/tropical continental flash rate ratio matches observations).
- Resulting flash rate data sets were normalized to match v1.0 LIS/OTD annual average climatological flash rate
- Test run of GMI model with three sets of met. fields for January-March with 5 TgN/yr from lightning.

Summary

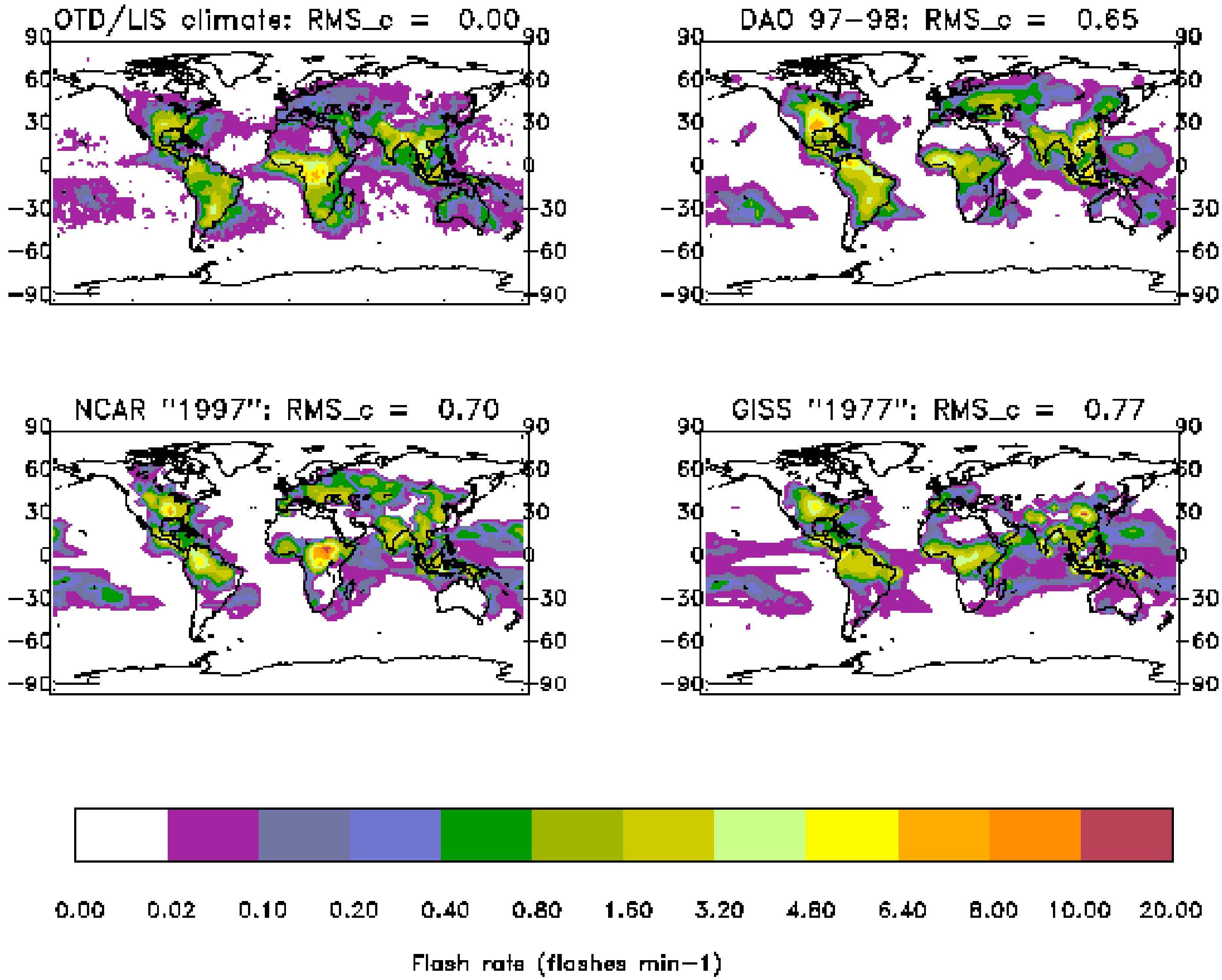
PRELIMINARY FINDINGS

- DAO: larger upper tropospheric NO_x and O_3 mixing ratios in mid latitudes and smaller in tropics compared with ISCCP-based climatological lightning.
- NCAR: relatively small differences at 400 hPa; larger differences at 250 hPa, with slightly less NO_x and O_3 at mid and high lat. and more in tropics.
- GISS: large reductions of NO_x at high N latitudes and in SH tropics at 250 hPa; less ozone in tropics and midlatitudes

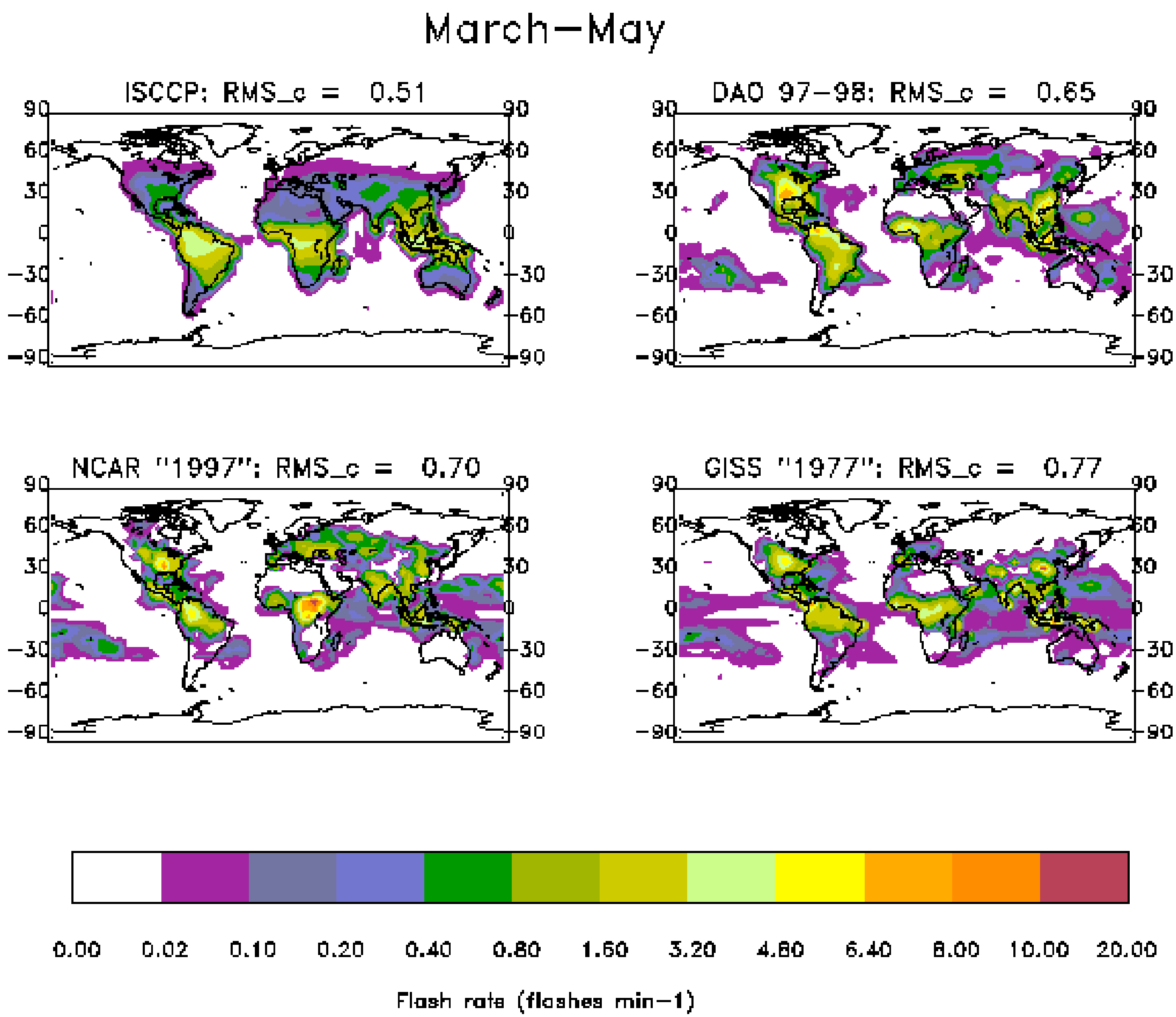

December−February
OTD/LIS climate: RMS_c = 0.00
DAO 97−98: RMS_c = 0.56
NCAR "1997": RMS_c = 0.70
GISS "1977": RMS_c = 0.57
90
60
30
0
−30
−60
−90
0.00
0.02
0.10
0.20
0.40
0.80
1.60
3.20
4.80
6.40
8.00
10.00
20.00
Flash rate (flashes min−1)


December–February
ISCCP: RMS_c = 0.50
DAO 97–98: RMS_c = 0.56
NCAR "1997": RMS_c = 0.70
GISS "1977": RMS_c = 0.57
90
60
30
0
−30
−60
−90
0.00
0.02
0.10
0.20
0.40
0.80
1.60
3.20
4.80
6.40
8.00
10.00
20.00
Flash rate (flashes min−1)

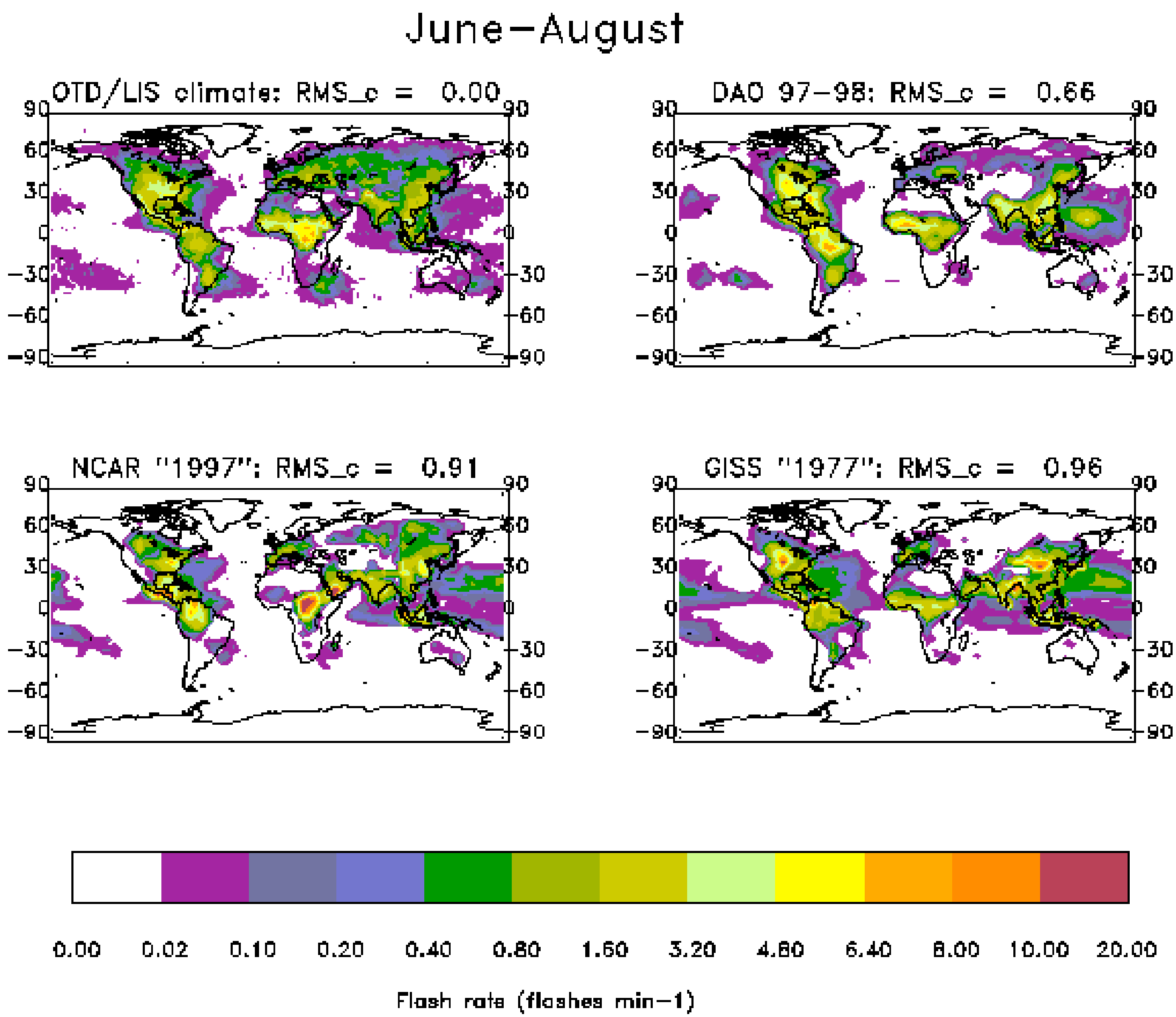
March–May

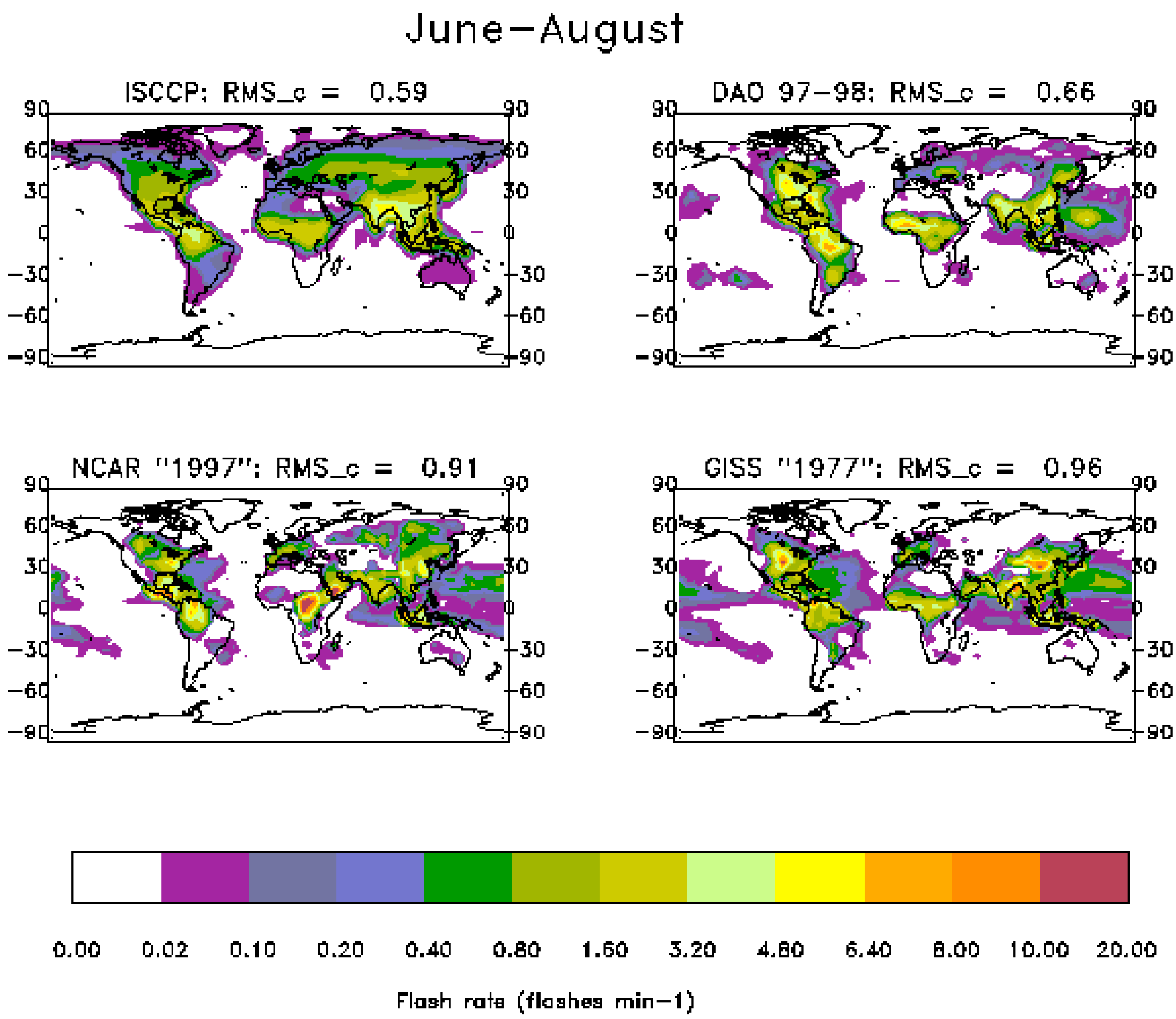


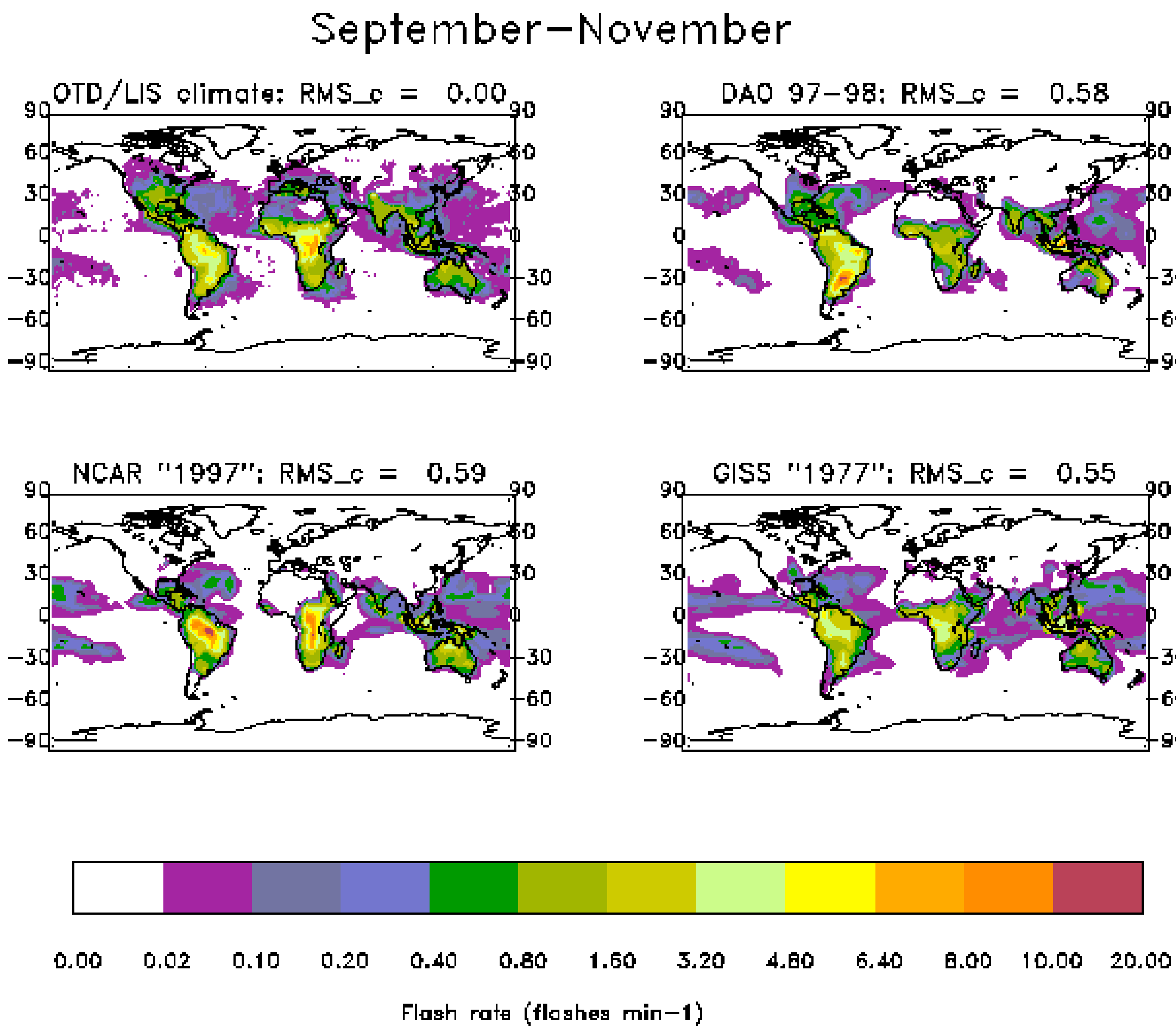
OTD/LIS climate: RMS_c = 0.00
DAO 97–98: RMS_c = 0.65
NCAR "1997": RMS_c = 0.70
GISS "1977": RMS_c = 0.77
90
60
30
0
−30
−60
−90
0.00
0.02
0.10
0.20
0.40
0.80
1.60
3.20
4.80
6.40
8.00
10.00
20.00
Flash rate (flashes min−1)

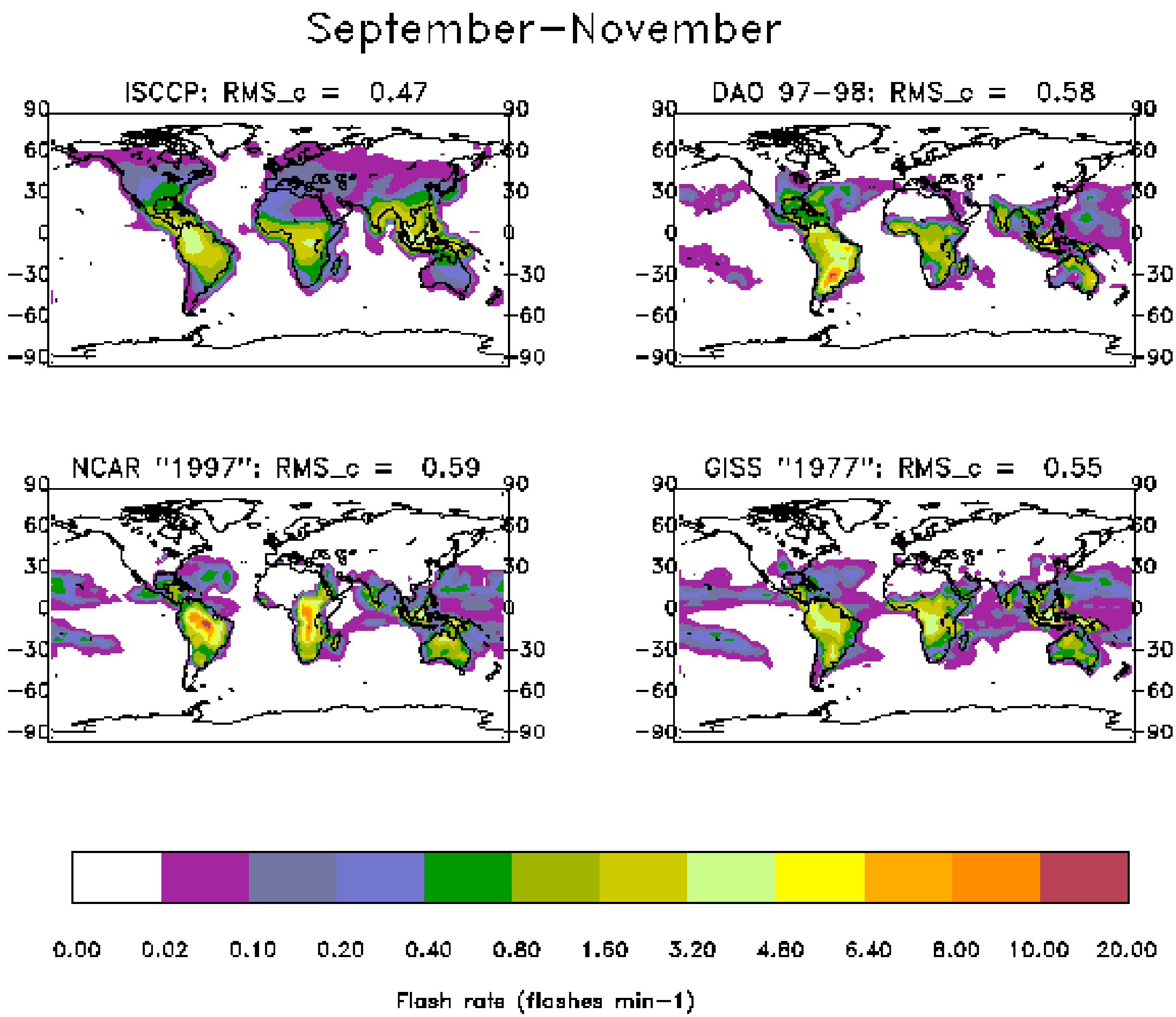


March–May
ISCCP: RMS_c = 0.51
DAO 97–98: RMS_c = 0.65
NCAR "1997": RMS_c = 0.70
GISS "1977": RMS_c = 0.77
90
60
30
0
−30
−60
−90
0.00
0.02
0.10
0.20
0.40
0.80
1.60
3.20
4.80
6.40
8.00
10.00
20.00
Flash rate (flashes min−1)


June–August
OTD/LIS climate: RMS_c = 0.00
DAO 97–98: RMS_c = 0.66
NCAR "1997": RMS_c = 0.91
GISS "1977": RMS_c = 0.96
0.00 0.02 0.10 0.20 0.40 0.80 1.60 3.20 4.80 6.40 8.00 10.00 20.00
Flash rate (flashes min–1)


June–August
ISCCP: RMS_c = 0.59
DAO 97–98: RMS_c = 0.66
NCAR "1997": RMS_c = 0.91
GISS "1977": RMS_c = 0.96
90
60
30
0
−30
−60
−90
0.00
0.02
0.10
0.20
0.40
0.80
1.60
3.20
4.80
6.40
8.00
10.00
20.00
Flash rate (flashes min−1)


September–November
OTD/LIS climate: RMS_c = 0.00
DAO 97–98: RMS_c = 0.58
NCAR "1997": RMS_c = 0.59
GISS "1977": RMS_c = 0.55
90
60
30
0
−30
−60
−90
0.00
0.02
0.10
0.20
0.40
0.80
1.60
3.20
4.80
6.40
8.00
10.00
20.00
Flash rate (flashes min−1)



September−November
ISCCP: RMS_c = 0.47
DAO 97−98: RMS_c = 0.58
NCAR "1997": RMS_c = 0.59
GISS "1977": RMS_c = 0.55
90
60
30
0
−30
−60
−90
0.00
0.02
0.10
0.20
0.40
0.80
1.60
3.20
4.80
6.40
8.00
10.00
20.00
Flash rate (flashes min−1)